Maine's Forest Insect and Disease Historical Database: Database Development and Analyses of 16 Years (1980-1995) of General Survey Data

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Introduction

The Maine Forest Service has amassed a large volume of forest insect and disease data which has been stored on the original handwritten paper records in cardboard boxes often housed in building attics and basements. These records include data originally collected for forest pest control activities, (1921-1995), a general statewide forest insect and disease survey (FIDS) (1941-1995), surveys for specific pests, such as European larch canker *(Lachnellula willkommii)*, and reports filed by Insect and Disease Management (I&DM) staff and cooperators. In all, there are over 80,000 records, representing more than 150,000 individual insect or disease entries. This information was utilized at the time of its collection to monitor the distribution and population levels of forest pests. These data are potentially valuable today as a long-term continuous record of the statewide incidence of forest insects and diseases.

It is a tedious, time-consuming process to extract information from the written records in their original form. However, conversion of these data to an electronic format will allow for efficient and accurate data summaries, statistical analyses and mapping (Power, _). In this new format, data can be reviewed to determine trends in the abundance, distribution, host associations, and diversity of insects and diseases over long time periods. These data may be helpful in present efforts to examine effects of global climate change on biodiversity or to determine environmental impacts of specific land-use practices.

In 1994, we initiated a feasibility study to determine the amount of effort required and the utility of transferring the handwritten Maine Forest Service (MFS) Forest Insect and Disease Survey data to an electronic database designed specifically for this purpose. A subset of the data was selected to be summarized and statistically analyzed to evaluate the utility of these data for describing trends in forest insect distribution and abundance within the state. The specific objectives of this project were: 1) to review and analyze the data entry process itself, 2) to quantify spatial and temporal variations in taxa incidence and abundance, 3) to explain variations among observers and sampling methods, and 4) to evaluate the value of the database and output products for research and pest management.

Methods

Data Collection

Sampling for the general insect survey was done primarily by 'branch beating' in which a sheet was placed beneath a tree to collect insects dislodged when branches were struck with a stick. Records also were generated by staff and cooperators visually checking trees and collecting specimens after observing a problem in an area. Specimens were sent to the MFS Insect & Disease Laboratory in Augusta where they were identified and cataloged. Observations reported by I&DM staff were also included. FIDS data collected from 1980-1995 were selected for this feasibility study.

Database Design

The historical database application was developed in Lotus Approach® (Lotus Corp.), a relational database program. Information entered into the system can be retrieved in a variety of ways to show different associations among variables. For example, all locations where a particular insect or disease have been found can be listed or all insects found in any location of interest could be listed. Information can also be retrieved by any combination of variables such as host species, stand type, date, observer, etc. Data are stored in a series of files that can be read by other database programs such as Access® or Progress®. The information also can be easily downloaded to spreadsheets, analytical programs and Geographic Information Systems (GIS) programs for interpretation.

The database is composed of a set of *tables* with each table containing variables or *fields* that define the data set. The tables are connected by common fields (Fig. 1) and accessed by different *views* of the database. This allows one to work with selected portions of the data, thus facilitating data retrieval. Each view has *lists*, *reports* and *forms* that can be set up to perform various functions. The historical database is composed of 14 linked tables; five active tables where new data are stored and nine static 'look up' tables that provide information that is used repeatedly.

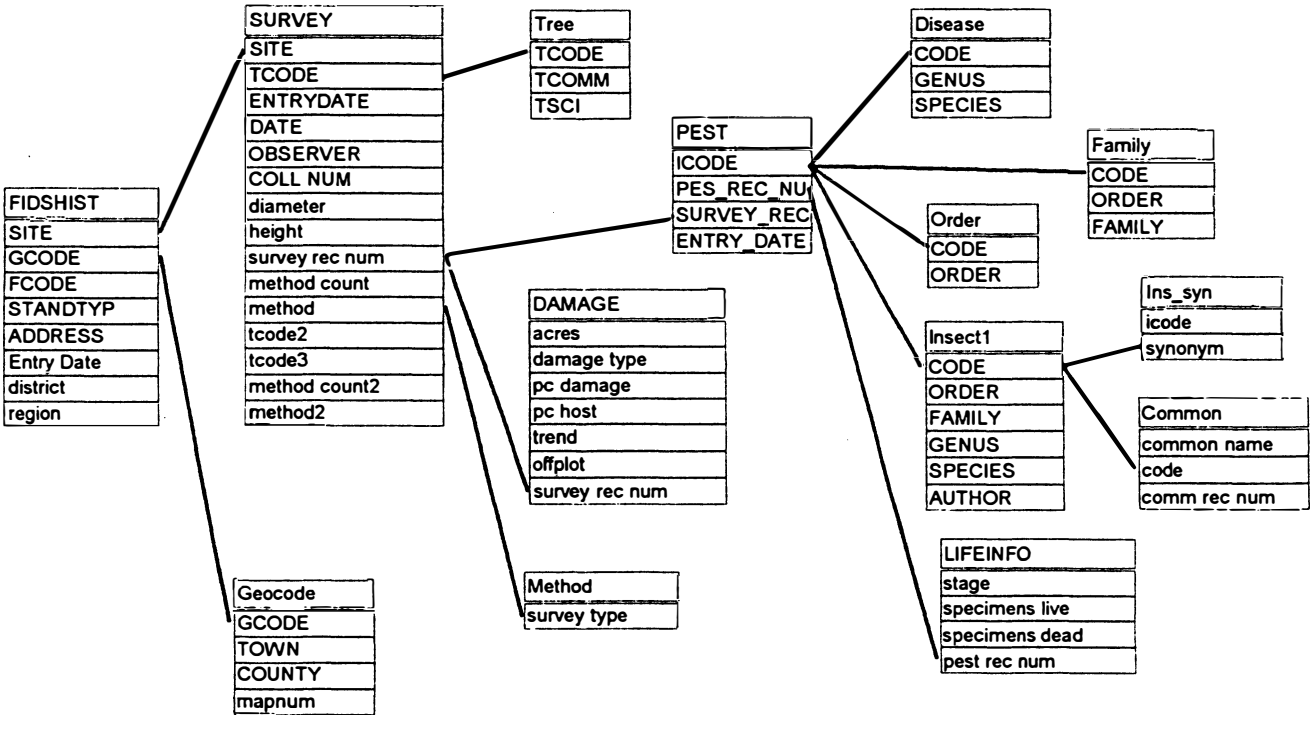


Figure 1. Schematic of MFS historical relational database structure.

The most important static tables store the taxonomic information for forest insects and diseases. This extensive catalog of 10,000 insects and 6,700 diseases was obtained from the Canadian Forest Service whose forest insect and disease survey is similar to the MFS general FIDS

program. As Maine and the eastern Canadian provinces have similar forest types and associated biota, the majority of insects and diseases found in Maine forests are listed in these tables. Other potential catalogs of insect and disease taxa were incompatible with database format or did not include many of the organisms found in Maine forests. Using a list that was already created has saved many hours of data entry, checking and correcting. The insect and disease tables are linked to the active tables by a numeric hierarchical code; a unique code for each taxa included in the table. Associated with the insect table are four other minor tables. Three of these are short tables, one each for order, family, and common names, to facilitate data entry. The fourth table lists taxonomic synonyms which allows the historic records to be entered as written and then updated to current taxonomic names.

Collection points are identified by township and associated with a geocode that can be used in GIS mapping. The geocode links the static township table to the active tables. Some townships in Maine have changed names or have two recognized names so both names have been placed in the static township file along with the county in order that information may be entered or retrieved by either an old or new township name or the county. The other two static tables are the host table and methods table. The host table contains a list of trees occurring in Maine. The methods table contains specific methodologies used in collecting data and, although it is not currently being utilized for the historical data, provides specific details on collection methods.

The active tables are designed to make the database as flexible as possible to allow for entry and retrieval of various types of insect and disease information. The primary table contains location information that does not vary over time. Therefore light trap or plot locations that remain the same over time would not have to be reentered each time a survey is conducted. The survey table contains information about a specific survey occurrence. The date, host, method, etc. can vary for multiple surveys for the same location and all be associated with the same location record or, as with the data in this FIDS project, there can be a single survey record for a particular location. In the future, data from light trap and plot work will be added and at that time the separation of the two tables will become more meaningful. The damage table contains host conditions found during a survey. Multiple organisms from a single survey can be entered into the pest table. The lifestage table contains insect life stages and number of specimens collected. Multiple lifestages can be entered for a single pest, i.e. 11 spruce budworm larvae and 3 pupae.

Data Entry

The MFS insect and disease data are handwritten on collection slips. The front side of each slip had site, damage and survey information on it with insect and disease identifications written on the back. Each slip was assigned a unique collection slip number when it was processed at the lab. These numbers were also included on many of the pinned specimens in an insect collection maintained at the MFS Insect and Disease Laboratory. A series of data entry screens were designed to match each of several different paper forms used over the years. We found that this increased both speed and accuracy of data entry. Students at the University of Maine entered the data thus providing a learning opportunity and income for students while keeping labor-costs for the project at a minimum.

Protocols were established for handling various types of identifications, such as those lacking scientific or officially recognized common names. A reference list was developed to provide family, order, or class names for organisms reported by unofficial common names such as 'looper caterpillar' or 'gnat'. Frequently encountered names were added to the database's common names table to facilitate data entry. Identifications were entered at the highest level of classification as was possible to determine from handwritten records. Records for which no further classification were possible are entered simply as 'insect' or 'disease'. Data recorded as insect-caused damage that lacked the causal organism itself were entered as 'damage' except for specific galls which are considered to be an accurate representation of the causal insect. Samples from which no insects were found were included in the data set as a 'negative find'. At present, all records are being entered into the database with the exception of negative finds for specific disease surveys, such as Eastern larch canker surveys.

During project development, data entry and error-checking processes were evaluated for efficiency and accuracy leading to a number of improvements in protocol and database design. For instance, we found that many of the handwritten records used alternative or outdated township names not present in the database. Other challenges to data entry were that handwritten insect and disease names were difficult to read, or were abbreviated requiring students entering the data to become familiar with their meanings. Adding approximately 50 commonly encountered taxonomic terms and alternative town names to the static tables improved data entry time. Modifying survey method fields to facilitate data entry reduced data entry errors and modifying report generating files facilitated error-checking. In addition, constraints were imposed in the data entry screens to prevent some errors of omission or duplication. Students were active participants in this effort as they worked with us to develop, evaluate and make suggestions for improvement in the data entry and quality control protocol. On average, it took 3.6 minutes to enter, check and correct the data from each collection slip with approximately 20% of this time spent on quality control.

Quality control protocol consists of specific error-checking routines that search for and correct common types of errors followed by a comparison of each record against the original data. A number of shortcuts, including checking random subsets of the data, were tested but we found that the error rate for experienced workers was at least 5%, therefore, all records in the database were checked for errors.

The database was backed up to floppy disks at the end of every data entry or correction session. In addition, copies of the database were periodically made on 100 megabyte portable storage disks and transported to the MFS offices in Augusta.

Data Analysis

Sixteen year's of data (1980-1995) were selected for summary, analysis, and examined for compatibility with a GIS program. Data were exported from Approach® formatted as a Dbase IV flat file. This file was then imported into a spreadsheet/graphics program (Excel®, Microsoft Corp.) and a statistical analysis program (SAS®, SAS Institute Inc.). Summarized data were exported from SAS in a Dbase IV format then imported into Excel to produce data summaries. Insect abundance, distribution, and diversity were mapped using GIS software (ArcView® 2.1,

Environmental Systems Research Institute). These maps include boundaries for 19 ecological unit subregions within the state of Maine (Keys, et al. 1995) and were provided by the USDA Forest Service. Maine state and township political boundaries were obtained from the Maine Office of Geographical Information Systems. Only insect data from 'branch beating' samples were included for the abundance, diversity, trends and distribution analyzes. Data collected by other methods were excluded because they lacked a discrete sample unit. Because the number of taxa per collection was found to be correlated with sample size (number of trees beaten), the number of taxa obtained was standardized for different sample sizes by dividing the number of taxa by the number of trees beaten for each sample.

Taxa Abundance

The incidence of taxa are represented as proportions calculated as the frequency of occurrence of each taxon within each township and year divided by the sampling frequency for the corresponding township and year. Each taxon reported for each observation was recorded as a single present or absent record without regard to the number of specimens reported in the sample.

Taxa Diversity

The Shannon Index (H') (McGurran, 1988), a widely-used index of taxa richness and diversity, was calculated for each of the ecological unit subregions within Maine for all years combined using the formula:

H' = sum(pi x ln(pi))

where: **pi = ni/N**

ni = frequency of the ith species

N = combined frequencies of all species.

The Shannon Index was then calculated for each ecological unit subregion for each year and the effect of year on diversity was tested by Analysis of Variance. Mean separations were tested using Tukey's test (SAS Inst. 1985).

Temporal Trends

Temporal trends in the frequencies of the 15 most frequent insect species collected by branch beating were examined by Chi-square analysis. The hypothesis of no significant change in incidence over the entire 16-year period, as well as for the 10-year period from 1980-1989, was tested by comparison of the calculated Chi-square statistic with the critical value for the appropriate degrees of freedom for each species.

Spatial Distribution

The spatial distribution and abundance for three insect species, spruce budworm (*Choristoneura fumiferana*), gypsy moth (*Lymantria dispar*), and yellowheaded spruce sawfly (*Pikonema alaskensis*), were mapped using ArcView.

Sampling Method Analysis

The proportion of records reporting each of the ten most frequently encountered insect taxa were compared across sampling methods by Analysis of Variance. Tukey's test was used for mean separations.

Observer Analysis

Sample size (number of trees sampled per collection), number of insect and disease taxa reported for each collection and for all collections pooled, and the sampling frequency (number of collections) were summarized by observer. Means and standard errors of these counts were calculated. The distribution of log-transformed counts (number of taxa, sample size, sample frequency) were examined. Correlations among these variables were examined. Sampling frequency and size were regressed against number of taxa reported.

Results

Data Entry and Quality Control

Summary statistics for the 1980-1995 data are shown in Table 1.

Table 1. Summary statistics for FIDS data 1980-1995.

Sampling Method	**Number of Collection Records**	**Number of Insects and Diseases Reported**
'Trees Checked' & unknown	2,549	4,381
'Branch Beating'	1,926	5,440
'Observations'	525	553
Total	5,000	10,374

Data Analysis

Taxa Abundance

There were 785 different insect taxa representing 17 orders, 149 families, 463 genera, and 528 species. There were also five families, nine genera, and ten species of mites and 108 different taxa of tree diseases reported.

Taxa Diversity

Taxa diversity across the entire period for each ecological subregion is shown in Fig. 2. Diversity was highest in the largest subregion (212Da = Central Maine Embayment Section), least in the smallest ecological subregion (221Ai = Gulf of Maine Coastal Plain Subsection) and intermediate in the intermediate-sized subregions indicating a clear trend for diversity increasing with area.

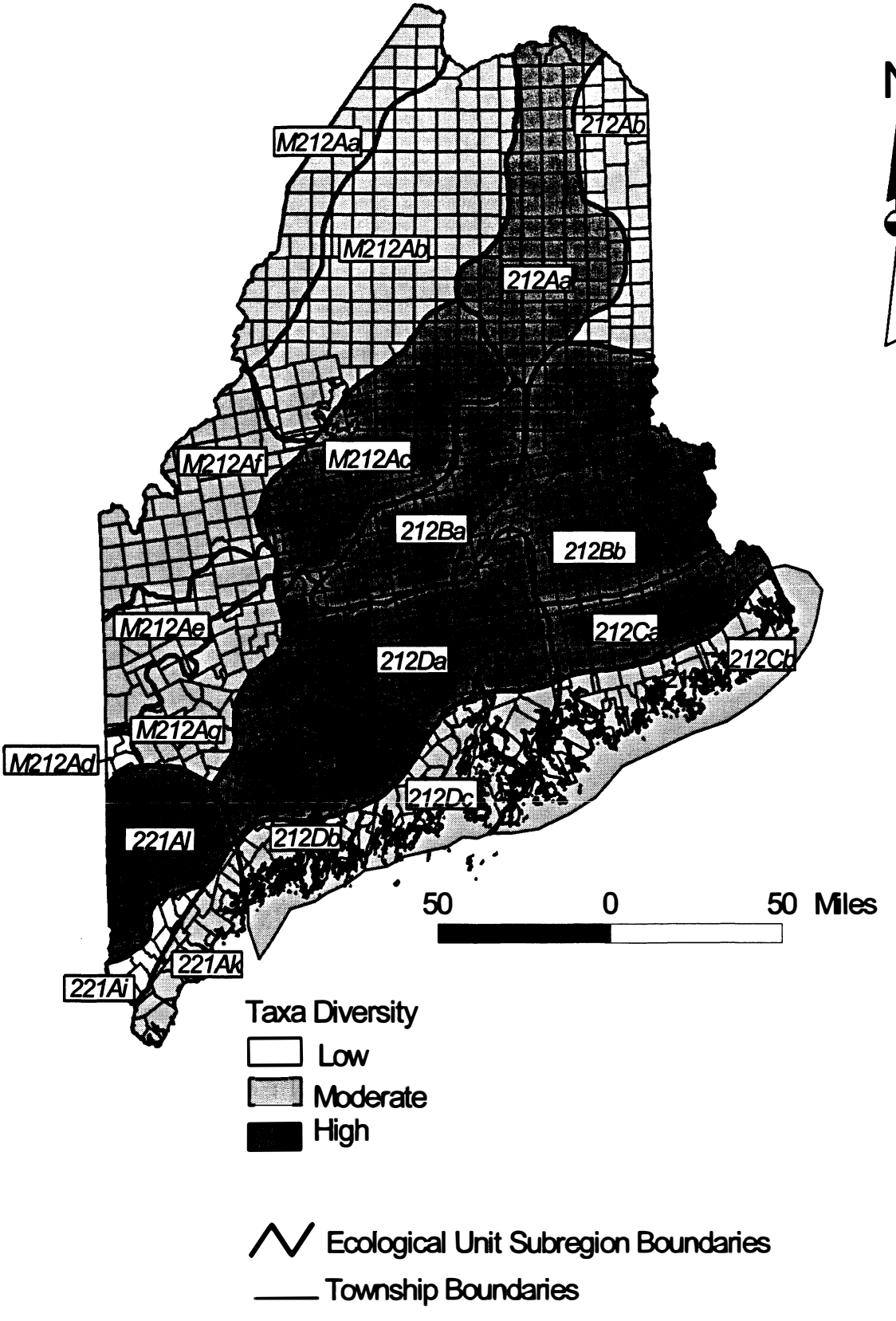
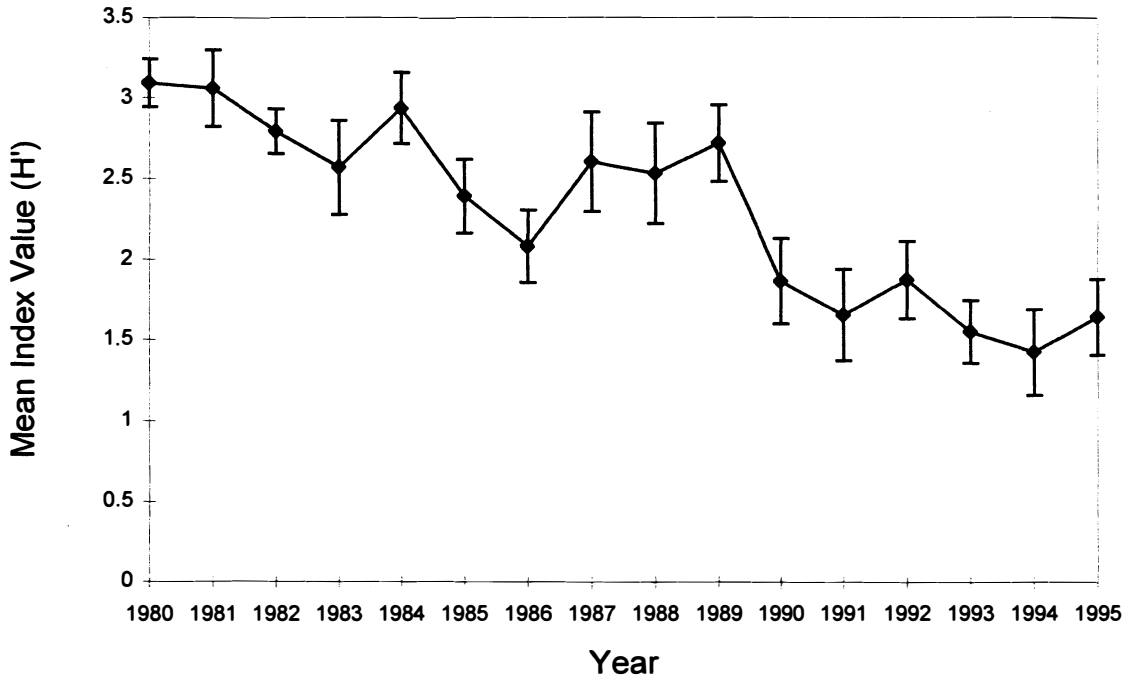


Figure 2. Mean taxa diversity by ecological unit subregion, 1980-1995, as measured using Shannon diversity index (H'). Low diversity = H' less than 3.5, Moderate diversity = H' between 3.5 and 4.5, High diversity = H' greater than 4.5. Ecological unit subregion designations from Keys et al. 1995.

Correlations between sample area size and diversity are not unexpected and have been reported for a number of other studies (McGurran 1988).

Diversity varied significantly with year ($F = 5.21$, $df = 258$, $P = 0.0001$). However, the number of samples also varied over the 16-year time period examined which very likely influenced our diversity estimates. Although we found a significant trend of declining diversity over time even when the most sparsely sampled years (1990-1995) were excluded ($F = 4.71$, $df = 1$, $P = 0.03$) (Fig. 3) this may be related to reduced sample size rather then a true indication of declining diversity. This is further supported by the fact that the two years of greatest diversity (1980 and 1981) were also the years with the greatest numbers of samples.

Figure 3. Changes in mean (± se) Shannon Diversity Index (H') for 1980-1995.



Although the sample size for each township and year is too small to determine trends in insect diversity on a fine scale, these analyses demonstrate the potential value of historical data for investigating trends in insect taxa diversity among different ecological regions and/ or over time as long as sample and area size are taken into account. It is likely that analyses of the entire data set spanning the period from 1941-1995, if adjusted for sample and area size, will yield meaningful information regarding trends in forest insect diversity in Maine.

Temporal Trends

The yearly incidence of the 15 most frequently collected insects obtained by the branch beating method was examined. Incidence fluctuated significantly over time for five of these taxa: forest

tent caterpillar, *Malacosoma disstria,* (X^2 = 10.2, P= 0.0014), spruce budworm, (X^2 = 91.18, P < 0.00001) (Fig. 4), a geometrid moth, *Eupithecia sp.* (X^2 = 4.04, P = 0.04), a cantharid soldier beetle, *Podabrus sp.* (X^2 = 13.38, P = 0.0003), and an aphid, *Cinara sp.* (X^2 = 22.9, P < 0.00001). Spruce budworm and forest tent caterpillar are major forest pests that are monitored by the MFS. Annual MFS reports describe the population levels and damage caused by these insects as rising in the 1970's then diminishing over the early 1980's (MFS 1979-1986 and Trial 1989). The frequencies of occurrence of the remaining ten taxa *(Limonius aeger, Anatis mali, Dalopius* sp., *Gilpinia hercyniae, Ctenicera triundulata, Aphrophora cribrata, Coleophora serratella, Lymantria dispar, Dioryctria reniculelloides,* and *Semiothisa* sp.) did not fluctuate significantly over time (P > 0.05).

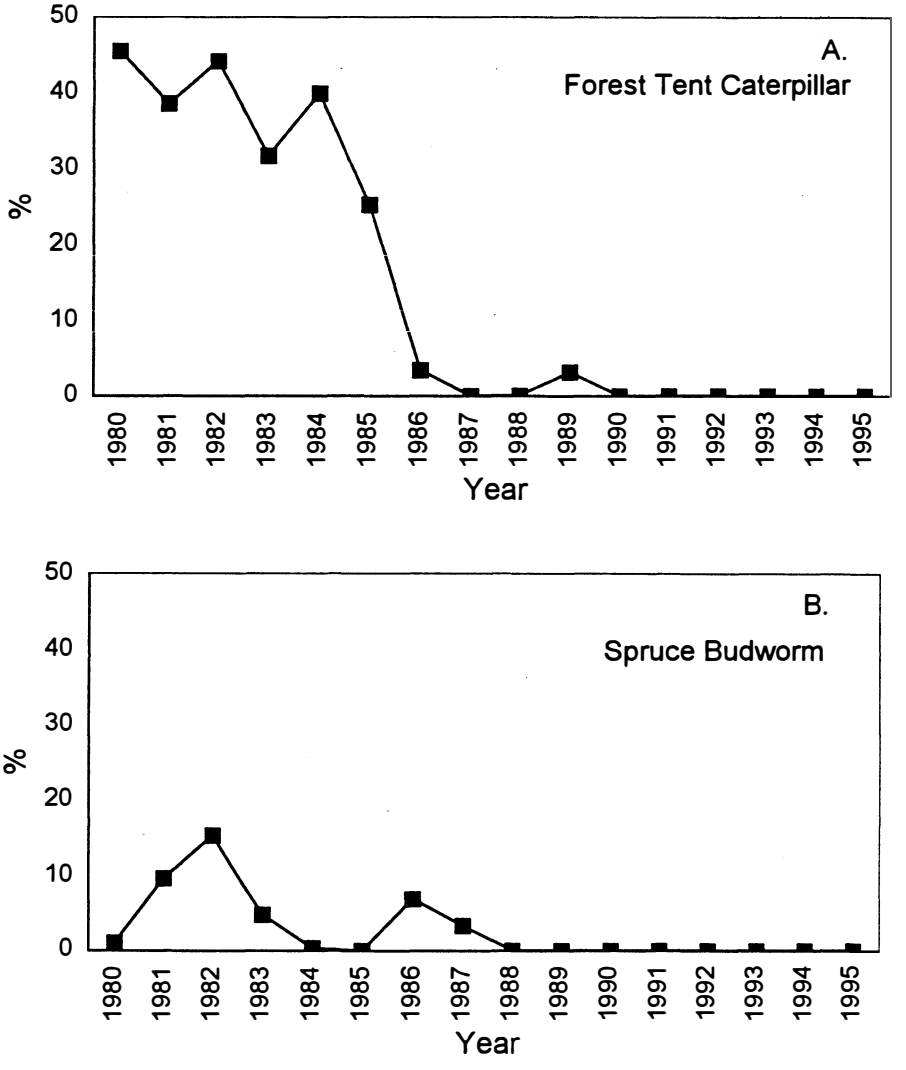


Figure 4. Percentage of branch-beating collections with forest tent caterpillar (A) or spruce budworm (B), 1980-1995.

Spatial Distribution

The spatial distribution map for spruce budworm in 1983 (Fig. 5) shows that the infestation was primarily in northern and downeast Maine. This correlates well with Trial (1989) who used a

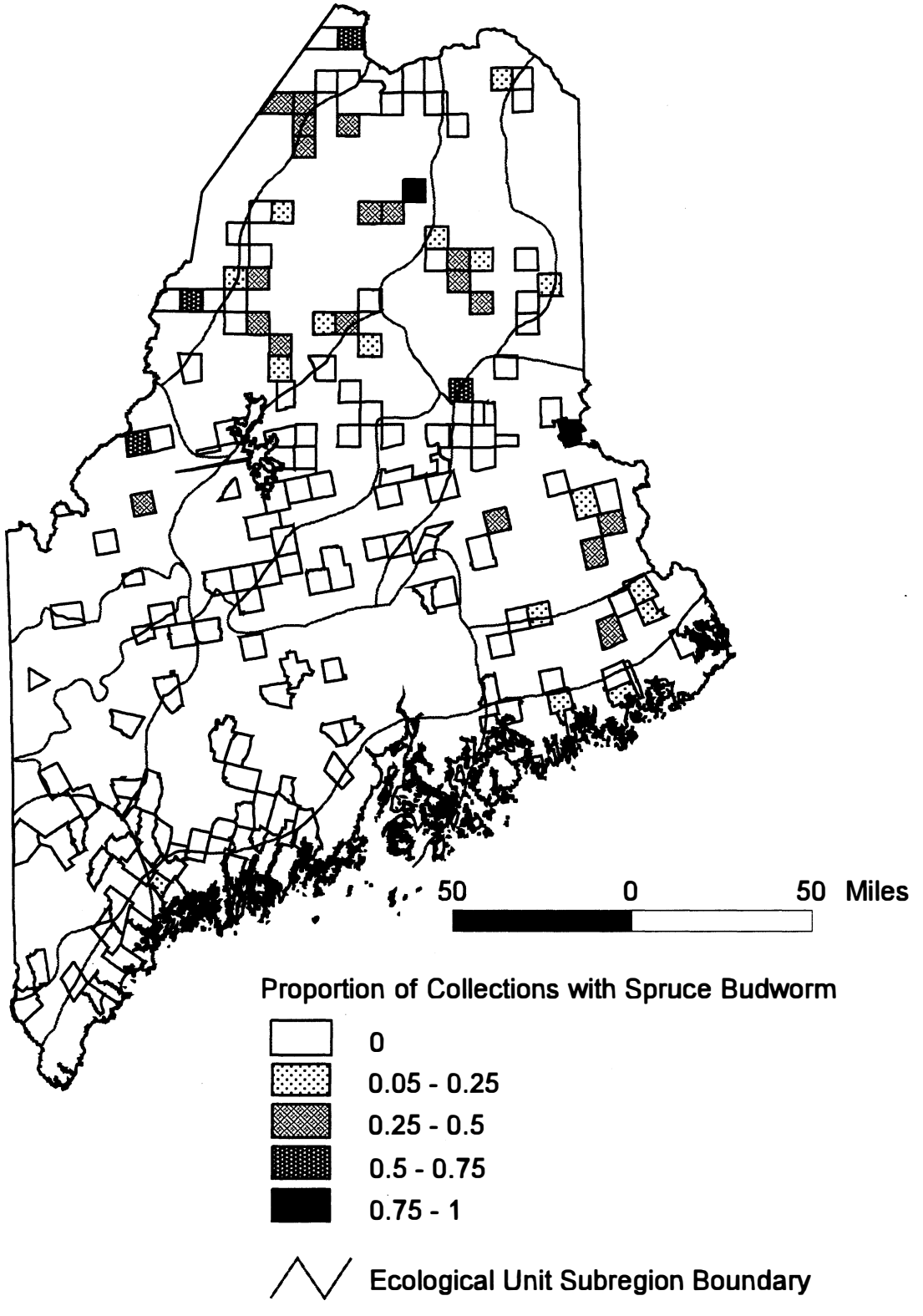


Figure 5. Proportion of branch beating collections in which spruce budworm was collected, shown for each town sampled in 1983.

variety of sources for spruce budworm distribution information and the range of spruce/fir forest type. Gypsy moth is restricted to southern Maine by climate and forest type and the FIDS data (Fig. 6) compares well with MFS defoliation maps (MFS, 1981). The proportion of collections containing yellowheaded spruce sawfly was less then 0.25 for any location (Fig. 7) and were recorded from widely scattered locations around the state. Yellowheaded spruce sawfly was not a significant problem during the time period analyzed (MFS, 1979-86). This is an insect that can be found in any year but not always at damaging levels.

Sampling Method Analysis

There were differences among sampling methods in terms of the frequency with which some insects were reported. Among the ten most frequently reported insects, taxa found significantly more frequently by the 'branch beating' method were *Choristoneura fumiferana*, ($F=3.41$, $df = 2$, $P = 0.038$) and *Dioryctria reniculella*, ($F = 17.8$, $df = 1$, $P = 0.0001$). Taxa found significantly more often by the 'trees checked' or 'observation' methods were *Malacosoma disstria* ($F = 16.9$, $df = 2$, $P = 0.0001$), *Lymantria dispar* ($F = 10.24$, $df = 2$, $P = 0.0001$), *Coleophora serratella* ($F = 24$, $df = 2$, $P = 0.0001$), *Operophtera bruceata* ($F=17.8$, $df = 1$, $P = 0.0002$), and *Lambdina fiscellaria* ($F = 5.71$, $df = 2$, $P = 0.0061$). Taxa for which there were no discernible sampling method effects were *Semiothisa* spp., *Podabrus* spp., *Eupithecia* spp., however, the comparison is less meaningful because there were few 'checked' and no 'observation' data for these taxa. Differing results among sampling methods are due to sampling objectives as well as biological and ecological differences among insects. For instance, because responses to landowner inquiries are often reported as 'observations' certain urban and shade-tree pests may occur more frequently by this method.

Observer Analysis

There were 120 observers using the 'branch beating' sampling method, 232 observers using 'trees checked' and 54 using 'observation' (Table 2). The number of reports recorded per observer ranged from one to 305 while the total number of taxa from all reports for a single observer varied from one to 270.

In general, the large number of observers did not appear to compromise the data. There were no outliers among observers in terms of the numbers of taxa per report or the number of taxa per tree per report. However, there was evidence that observer experience influenced the results, at least among 'branch beating' and 'trees checked' methods. For these two methods the mean number of taxa collected per sample was significantly correlated with mean sample size (number of trees sampled per collection) among inexperienced observers (those with fewer than three collections over the 16-year period) ($r = 0.244$, $P = 0.0056$), but not among experienced observers (those with three or more collections) ($r = 0.04$, $P = 0.70$). That is, inexperienced observers tended to find more different organisms at a site if they sampled more trees, but experienced observers found the same number of taxa regardless of the number of trees sampled.

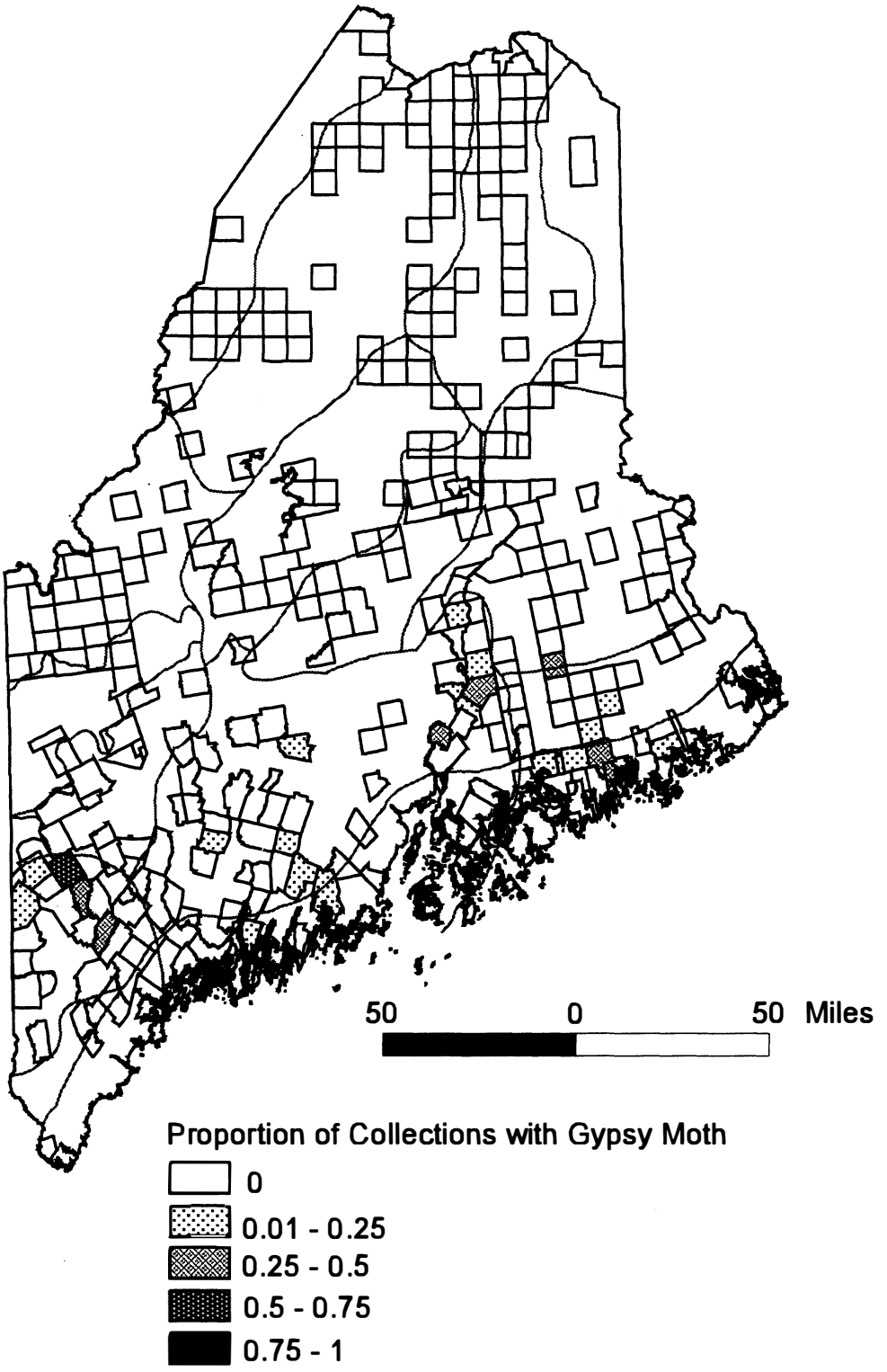


Figure 6. Proportion of branch beating collections in which gypsy moth was collected, shown for each town sampled in 1981.

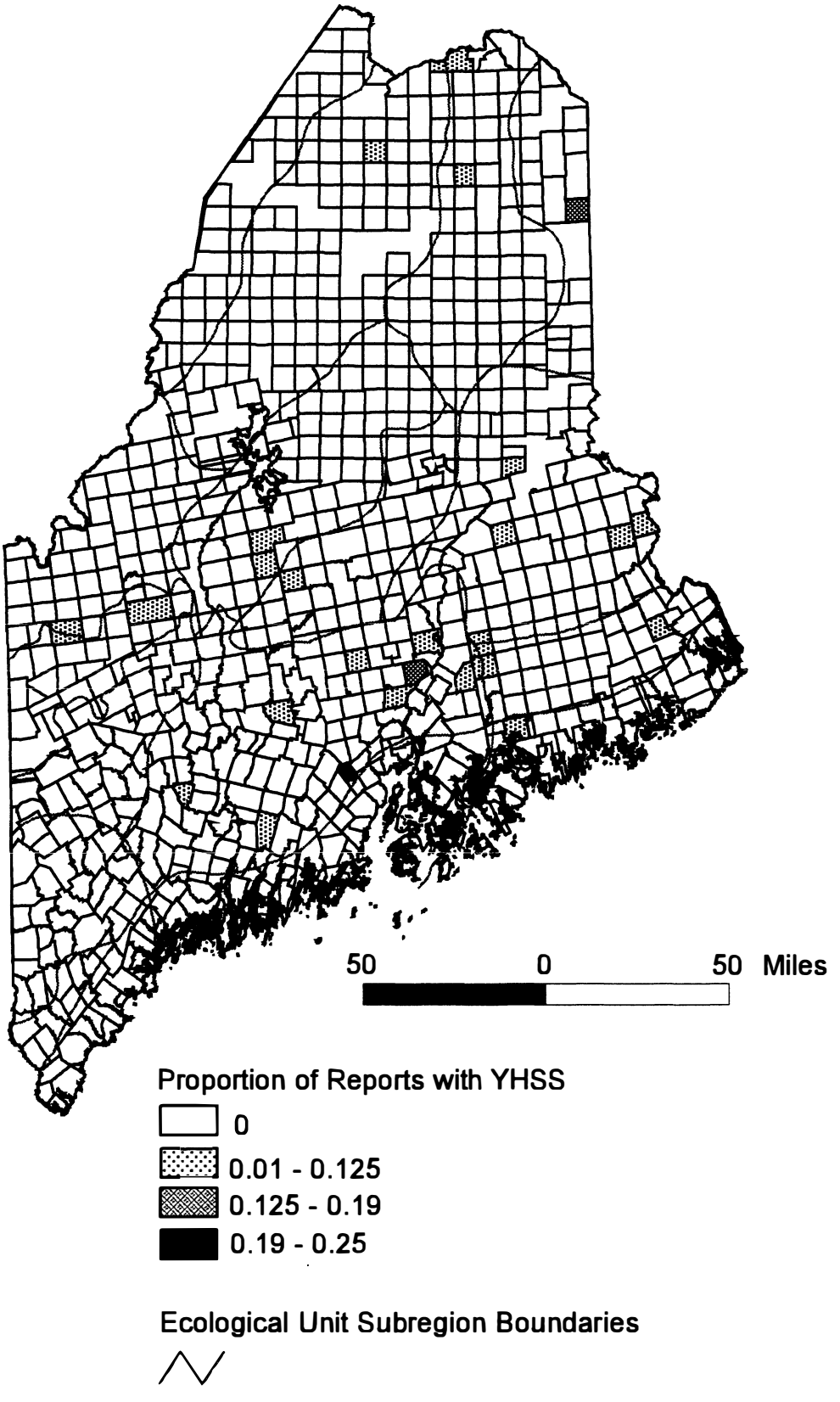


Figure 7. Proportion of all collections and observations reporting yellowheaded spruce sawfly, shown for each town sampled 1980-1995.

Table 2. Descriptive statistics for observer sampling profiles by method.

Variable	Mean	SE*	N**
Method = 'Trees Checked'			
Reports/Observer	10.72	2.26	232
Taxa Reported/Observer	9.59	1.8	232
Trees Sampled/Report	10.52	1.58	99
Taxa/Report	1.26	0.05	232
Taxa/Tree/Report	0.38	0.05	77
Method = 'Branch Beating'			
Reports/Observer	15.87	1.84	120
Taxa Reported /Observer	22.25	2.53	120
Trees Sampled/Report	3.28	0.26	116
Taxa/Report	1.65	0.08	120
Taxa/Tree/Report	0.74	0.06	116
Method = 'Observation'			
Reports/Observer	9.35	2.16	54
Taxa Reported/Observer	3.81	0.77	54
Trees Sampled/Report	20.24	4.25	37
Taxa/Report	0.69	0.04	54
Taxa/Tree/Report	0.2	0.05	37

*SE = standard error of the mean
**N = number of observations

The effect of observer experience was also indicated by a significant correlation between the mean number of taxa per report and the total number of reports made by an observer ($r = 0.24$, $P = 0.006$) among 'branch beating' and 'trees checked' methods, indicating that the number of taxa collected per sample tended to increase with increasing observer experience. There were no significant correlations among mean sample size, sample frequency, or mean number of taxa for the observers reporting 'observation' data.

Conclusions

Data Entry and Quality Control

The data entry process using customized data entry screens with our relational database is efficient. Data entry accuracy is greatly aided by imposing restrictions on each field, however,

each record must be checked again by comparison against the original data forms to detect and correct all errors. Additional errors were detected and corrected by using the query capabilities of the database software to detect common types of errors.

Compatibility with Other Applications

Data are easily exported from the database for use with several other software packages. Exported data was imported into Microsoft Excel and SAS (Statistical Analysis System) which allowed for quick and easy data manipulation for generating summaries, data analysis, mapping and graphical presentation. For mapping purposes, the geocodes incorporated into the database were compatible with GIS coverages obtained from other sources, thus no digitizing or other manipulations were necessary. Data summaries generated with SAS and/or Excel were easily joined with ArcView polygon attribute files, thus enabling geographical presentation of survey data.

Utility of Database for Statistical Analysis and Mapping

Survey data collected in a discrete sample unit such as those collected by the 'branch beating' method can be useful for detecting changes in the incidence and abundance of insects and diseases. Fortunately, during many years in which hundreds or thousands of specimens were collected, there was a good geographical distribution of 'branch beating' collections. These data were numerous and extensive enough to enable reliable estimates of distribution and abundance on the somewhat coarse spatial scale of townships.

The patterns of abundance of insect taxa among records reported as 'observations' or 'trees checked' were similar to those obtained by the 'branch beating' method, with a few notable exceptions. Despite the limitation that the sample unit cannot be easily determined for 'check' and 'observation' data, it is likely that there are a number of insect groups which, due to behavioral or other characteristics, will seldom be collected by branch beating. Therefore, the inclusion of data collected by the other survey methods provides a more diverse listing of insect taxa present.

With the compatibility of these data with GIS software, patterns in the distribution, abundance, and diversity of insect and disease taxa can be layered with weather, pesticide application, defoliation, land use, and other geographically referenced data within a GIS program. Thus, these data may be quite useful for describing the effects of weather patterns, land-uses, forest management practices, or other variables on forest insects and diseases. Such efforts are planned.

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